Civilian Defense

Protective Construction

STRUCTURES SERIES **BULLETIN No. 1**

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INTRODUCTION

This bulletin is published to present the general background necessary for intelligent consideration of the subject of protective construction. In no sense should issuance of this bulletin be construed as the signal to start work immediately on any of the protective structures described. Nevertheless, it is deemed essential that responsible civil officials and civilian engineers give thought to methods, plans, and especially procedures that can be followed in their respective localities should such protective structures become necessary in the future.

The material presented here has been prepared after close study of the latest information available from European sources, chiefly British, and it is intended as a general summary of this information. Many subjects are necessarily treated very briefly. Detailed data upon which designs can be based are being assembled from foreign reports and from tests being conducted in the United States. As this material is digested, it will be disseminated.

I. AERIAL ATTACK

The first part of this bulletin considers aerial attack. The major subdivisions under which the subject is treated are as follows: the weapons used, ballistics, and effects of bombs.

A. WEAPONS USED

The weapons against which protection must be provided in protective construction are (1) aerial bombs; (2) machine gun and rifle fire and fragments from antiaircraft shells.

Aerial bombs may be classified according to purpose as:

1. Demolition bombs.
2. Fragmentation bombs.
3. Gas bombs.
4. Incendiary bombs.
5. Armor piercing bombs.
6. Aerial mines.
7. Aerial gunfire.

1. Demolition Bombs

Demolition bombs are designed for the primary purpose of demolishing buildings and other structures. They range in weight from 50 to 4,000 pounds, about half the weight being the explosive. Bombs of this class in the smaller and medium sizes are used against ammunition dumps, light structures such as dwellings, apartments, commercial and manufacturing plants, airdromes, and railroad tracks, while the heavier bombs are used against factories, harbor works, bridges, major fortifications, and naval vessels. Bombs in the larger sizes may be used against any target but it is not generally economical to do so. In the attacks on European cities, the majority of bombs dropped have not exceeded 550 pounds in weight. Large bombs intended for factories or railroad yards may land in a residential district, even when no civilian bombing is intended.

2. Fragmentation Bombs

Fragmentation bombs, which weigh from 17 to 30 pounds, are effective chiefly against personnel. They can be used against aircraft on the ground, searchlights, and any other targets which are easily damaged or destroyed by fragments, although demolition bombs are generally used for these purposes.

3. Gas Bombs

Gas bombs are usually much smaller than demolition bombs and their effects on structures are much less. They affect the design of air raid

shelters chiefly in making necessary gastight inclosures, gas locks, and a more comprehensive system of ventilation than would be required for normal conditions.

4. Incendiary Bombs

Incendiary bombs, usually weighing from 2 to 100 pounds, are composed principally of magnesium, thermite, oil, or other highly incendiary material, and are used chiefly against easily inflammable targets such as congested dwelling areas in cities, munitions dumps, etc. Some phosphorus bombs have been developed and used in certain instances.

5. Armor Piercing Bombs

Armor piercing bombs have heavy cases, designed for maximum penetration, and have a smaller proportion of explosive than demolition bombs. Past experience does not indicate their use except against highly resistant targets.

6. Aerial Mines

Aerial mines are very large bombs weighing approximately 2,000 pounds similar in design to submarine mines. They are released with a parachute and detonate on impact and produce intense blast effect. They may be used against miscellaneous targets, including densely built up residential areas.

7. Aerial Gunfire

An aerial attack may include machine gun and cannon fire, in addition to bombardment. Present-day military aircraft mount .30 and .50 caliber machine guns, and cannon as large as 37 millimeter. Structures designed to give protection from bomb splinters will probably be immune to aircraft machine gun fire. Aerial gunfire against ground structures is of relatively little importance in comparison with the danger of bombs to ground structures.

Fragments of antiaircraft shells, which fall from considerable heights, attain velocities sufficient to cause injuries to unprotected personnel and to such portions of buildings as light tile roofs, skylights, windows, etc.

B. BALLISTICS

1. Trajectory and Angle of Impact

The trajectory of a bomb released from an airplane in a vacuum would be a parabola. In air, however, the parabolic path is modified in shape and slightly affected by the size and density of the bomb. The angle of impact is dependent on the elevation of the plane and its speed. Table 1 (page 2) gives approximate angles of impact for

varying altitudes and speeds for demolition bombs weighing from 100 to 2,000 pounds. The values given are for no wind conditions and are accurate within about 1 percent for the range of sizes given.

TABLE 1.—Degree of angle of impact with the horizonal for demolition bombs, by altitude and airplane speed

Altitude (feet)	Airplane speed (miles per hour)					
	120	140	160	180	200	210
	Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
2,000	65	61	58	55	53	51
4,000	72	69	67	65	62	60
6,000	76	73	71	69	67	66
8,000	78	76	74	72	70	69
10,000	79	77	75	74	72	72
12,000	80	79	77	77	74	73
15,000	81	80	79	77	76	75
20,000	83	82	81	79	78	78

2. Impact Velocity

The impact velocity is also dependent on the elevation of the plane and its speed. It is relatively independent of the size of the bomb. Table 2 gives approximate impact velocities for varying angles and speeds for demolition bombs from 100 to 2,000 pounds. The values

TABLE 2.—Impact velocity (feet per second) of demolition bombs, by altitude and airplane speed

Altitude (feet)	Airplane speed (miles per hour)					
	120	140	160	180	200	210
	Ft. per sec.	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*
2,000	390	400	410	430	440	450
4,000	510	520	530	540	550	550
6,000	600	610	620	620	630	630
8,000	680	680	680	690	700	700
10,000	740	740	740	750	750	760
12,000	790	790	790	800	800	800
15,000	850	850	850	860	860	860
20,000	920	930	930	930	930	930

are for no wind conditions and are accurate within about 5 percent for the range of sizes given. Very heavy armor piercing bombs, which have high sectional pressures, have greater velocities, the maximum approaching 1,500 feet per second.

C. EFFECTS OF BOMBS

The immediate effects of an aerial bomb upon striking a target are impact and detonation. Impact may result in penetration, and detonation may result in blast (known as shock in earth or other solid media, or simply blast in air) and fragmentation of the bomb case.

1. Penetration

The amount of penetration of any bomb depends on its physical characteristics (shape, weight, dimensions, sectional pressure, strength of case, etc.), its striking velocity, the angle of impact, the physical properties of the material struck, and whether the bomb is equipped with an instantaneous or a delayed action fuse. In general, aircraft bombs have considerably less penetration than shells fired from guns. This is because the striking velocity is much less, and also because the bomb case is often broken up on impact with a resistant material. The penetration of bombs with instantaneous fuses is small.

The tendency of a delayed action bomb to deviate from a straight path in penetrating the earth should be noted. This phenomenon makes the detection and removal of unexploded bombs difficult, and affects the design of the foundations of buildings and shelters. Obviously, a bomb that penetrates a structure or the ground over or under a shelter before exploding will do much more damage than one exploding on impact. For this reason, delayed action fuses are generally used for demolition bombs.

Many attempts have been made to find an exact formula to express the depth to which a bomb will penetrate various media, but these have been largely theoretical. Empirical data are so scanty that thus far it is impossible to determine which of the various theories is nearest the fact, or indeed what constants can properly be used, if any; all of them can obviously be made to fit some of the obscure facts. Experimental determination of penetration parameters is in progress. Table 3, which follows, has been compiled from various foreign sources and from data of the Ordnance Department, United States Army, obtained from actual tests. This table gives approximate depths of craters, due to impact and explosion, for several sizes of light or medium case bombs in various media.

TABLE 3.—Depth of craters of delayed action bombs, by size of bomb and different media

Size of bomb	Earth, sand, gravel	Bricks or soft rock	Reinforced concrete, class A (3,400 pounds)	
			Total depths of craters where slab is continuously supported	Proof thickness [1]
	Feet	*Feet*	*Feet*	*Feet*
100-pound	5 to 10	3	1.2	2.4
300-pound	9 to 17	6	2.0	4.0
500-pound	12 to 23	8	2.6	5.2
1,100-pound	21 to 41	13	4.3	8.6
2,000-pound	30 to 57	18	5.8	11.6

[1] The "proof thickness" is taken as equal to twice the total depths of craters. This is recommended by British authorities to provide for the uncertainties of the calculation and for the effect of scabbing. This recommendation is believed to be safe and is probably excessive, especially in the larger sizes of bombs. Tests are planned which should give more exact data, and figures based on these tests will be made available in 1941.

When a projectile perforates a thin material, the diameter of the hole formed may be approximately equal to the diameter of the projectile, as for example when a bullet strikes a sheet of plate glass with high velocity. But if the target is a thick slab of concrete, the surface struck is generally damaged over a much greater area than that of the cross section of the projectile, and a crater is formed.[1]

The phenomenon termed *scabbing* consists in the flinging off, from the rear of the target, of a piece of the target opposite the part struck; scabbing may occur whether the target is perforated or not. Conditions necessary for scabbing are:

(1) A shock of high intensity caused by impact or explosion in close contact with target.

(2) A suitable relation between thickness of target and its tensile and shear strength.

Scabbing is reduced by continuous support underneath, such as might be provided if resting on sand. The degree to which such support affects scabbing is probably determined by the resistance to compres-

[1] This paragraph from Air Raid Precautions Department of the Home Office, *Structural Defence*, Air Raid Precautions Handbook No. 5, first ed. (London : His Majesty's Stationery Office, 1939), p. 17.

sion of the supporting material. The ultimate effect of the "scab" is to help the bomb perforate the target. The shape of a scab is usually similar to that shown in figure 1.

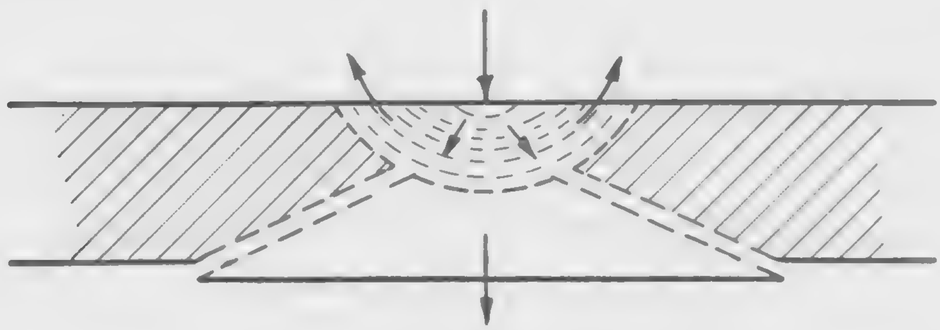


FIGURE 1.—Diagrammatic representation of scabbing

2. BLAST

By blast is meant the compression and suction wave which is set up by the detonation of high explosive. At every point in the neighborhood of an explosion there occurs first a momentary wave of high pressure (for about 0.005 seconds for a 500-pound demolition bomb), and then a negative "suction" pressure. Like the pressure component, the suction component of the blast wave lasts only for a fraction of a second, but as a rule it lasts for a longer period than the compression wave (up to 0.02 seconds for a 500-pound demolition bomb).

The approximate form of a pressure-time curve for the blast of a high explosive is shown in figure 2.

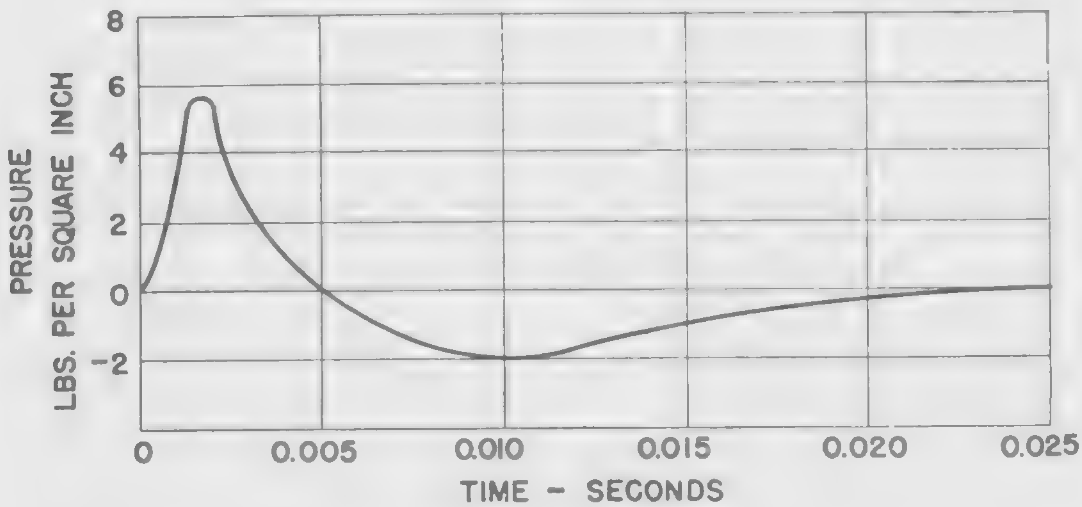


FIGURE 2.—Approximate form of a pressure-time curve for a 500-pound high-explosive bomb detonated at 50 feet

The blast wave may be considered as a shell of compressed gas increasing in radius with extreme rapidity. The pressure which the moving gas exerts on an object is the summation of the static pressure and pressure caused by its velocity. This is comparable to static and velocity heads in hydraulics. Any surface parallel to the direction of motion of the gas will be subjected to static pressure alone. Any surface facing the explosion will be subjected to pressure resulting from the velocity of the gases in addition to the static pressure.

The wave of pressure is highest in the region of the explosion and falls off rapidly the further it moves away. Close to the explosion the pressure may be as great as the static pressure. It falls off more rapidly with distance than does the static pressure. Everything in the immediate neighborhood of a big bomb therefore will be exposed suddenly to a violent pressure wave of many times atmospheric pressure, whereas, depending on the bomb, everything 50 feet away may be exposed only to two or three times atmospheric pressure. At 100 feet, the excess pressure may be only a fraction of an atmosphere.

The suction component of the blast wave is always much weaker than the pressure component, and in no case can it ever be greater than atmospheric pressure.

Thus all things in the immediate neighborhood of an explosion will first experience a violent increase of pressure which may tear them to pieces and blow them far from the scene of the explosion. Those objects not shattered by and blown in by the pressure wave may later be pulled toward the center of the explosion by the weaker suction wave because of the longer time for which this acts.

Outside the primary zone of explosion the disturbance sets up longitudinal waves in the air. These waves have the usual characteristics of wave phenomena in elastic media such as reflection and refraction. Structures affected by blast are seldom isolated but are usually grouped with others which interfere with the passage of the waves causing reflection and refraction. In streets, where the blast is to some extent confined in a narrow space, the blast wave undergoes successive reflections and a periodic disturbance is set up. The frequencies of the waves thus differ at various distances from the bomb and resonance with structural or nonstructural materials (such as window glass) may occur at considerable distances. As a result, windows at a distance may be broken, while those nearby subject to waves of different frequencies may remain undamaged.

3. Fragmentation

Fragmentation occurs when the bomb case is shattered by the explosion. Splinters from the case fly in all directions with initial velocities in some cases several times that of an ordinary rifle bullet (up to 5,000–7,000 feet per second), piercing brick and concrete walls and causing fatalities up to 200 yards. Because the fragments are of small size and irregular shape, they lose velocity rapidly and do not fly to great distances. If a bomb penetrates into the earth or a solid target before exploding, the danger from fragments will be greatly reduced, since the projection of fragments will be decreased by the surrounding material. Table 4 gives the thickness of various materials required to stop fragments of a 500-pound bomb at a distance of 50 feet. This table is based on tests made in England.

Table 4.—Thickness of various materials required for protection against fragments of a 500-pound bomb at a distance of 50 feet

Material	Required thickness
Mild steel plate	1½ inches.
Brick wall [1]	13½ inches.
Plain concrete	15 inches.
Reinforced concrete [2]	12 inches.
Specially reinforced concrete [3]	10 inches.
Sand or earth revetment	2 feet, 6 inches.
Gravel or stones between wood sheathing or corrugated iron.	2 feet, 0 inches.

[1] Recent tests indicate that this figure may be somewhat reduced.
[2] Normal structural reinforcement.
[3] Reinforced to resist high local stresses in diagonal tension.

Equivalent protection would be given by these materials suitably combined in proportionate thicknesses. This table is not exhaustive and doubtless other materials could be shown to be equally effective for the purpose.

4. Earth Shock

The maximum effect of earth shock occurs when a bomb with a delayed-action fuse penetrates a considerable distance into the earth before exploding. The shock is a wave of actual physical movement of earth radially from the center of explosion. The disturbance of the earth adjacent to the detonation is commonly known as "mining" effect.

5. General Effects of Bombs on Buildings

The effects of bombing on buildings are dependent on the type and size of bomb, the length of delay in the fuse, the height of release, the angle of impact, and the type and construction of the buildings affected. Apart from damage from impact and fire, the effects of high-explosive bombs are due to three factors: blast, fragments, and shock. Which of these three is the most important in a particular instance depends upon the other conditions enumerated above.

For purposes of analysis, the damage caused by bombs may be divided into primary and secondary damage. Primary damage is the direct result of the impact and explosion of the bomb; it results in damage to structual elements such as concrete, brick or stone walls, concrete or steel beams, and to nonstructural elements such as partitions, roofing materials, windows, doors, plaster, etc. Secondary effects are those resulting indirectly from primary effects, and include the collapse of structures where members have been destroyed by explosion or displaced by blast, or when falling debris has heavily overloaded undamaged members.

The effects of blast on nonstructural parts of buildings, such as windows, doors, plasters, ceilings, etc., depend upon many factors. The extent of confinement or obstruction of the blast wave plays an important role in the interior damage caused by an exploding bomb. In the immediate vicinity of the bomb the pressure wave tends to destroy walls by pushing them away from the explosion, while at a greater distance either pressure or suction, or both, will cause the partitions, windows, etc., to collapse toward the explosion. Usually plaster is stripped from ceilings and walls, windows and doors are blown from fastenings, and light partition walls destroyed; these effects occur even when bombs fall outside the building. In the latter case, the blast enters through the windows or other openings and acts on the interior panels. Failure occurs in the weakest portion of windows, doors, and panels. Whole window frames have been removed by blast and blown across a room, landing on a bed with the glass panes unbroken.

Vertical glass windows may shatter and fragments fall away from or toward the explosion. Fragments of broken glass constitute a serious danger to personnel. Glazed roofs in factory buildings are particularly vulnerable to damage, and breakage may interrupt production by interfering with black-out measures and damaging machinery. The shock from the blast wave acts very quickly and has been known to tear swinging doors free from their hinges rather than

cause the door to swing. In this connection it should be pointed out that blast vents that consist of light materials which are easily blown off, will not in general function to protect the rest of the structure in the immediate vicinity of a bomb explosion. In single-story industrial structures, blast waves may be reflected from roof coverings before the inertia of the roof can be overcome, effecting its removal.

Fragments of bombs ordinarily do not affect the structural stability of a building, but if a bomb explodes close to concrete beams or columns, damage may be quite severe, causing pieces of concrete to be broken away and exposing the reinforcing. Fragments may pierce ordinary partitions and walls (see table 4, page 8). They may also pierce light roof coverings and windows.

Structural damage from earth shock may be more serious than that resulting from blast alone. Extremely high accelerations have been recorded in the earth near a 550-pound test bomb. Masonry and brick load-bearing wall buildings fare very badly as a result of earth shock. Bearing walls are stable under usual loads for which designed, but when subjected to heavy lateral loads (such as may be produced by earth shock), they generally collapse. Obviously the bomb must penetrate the earth and explode underground before causing damage by earth shock.

Steel frame structures, when designed in accordance with the principle of continuity, with particular attention to conditions of fixity at points where beams and columns are framed together, suffer little from the effects of earth shock.

The so-called "knock on" effect caused by the impact of a direct hit and explosion should be distinguished from pure earth shock. This effect is a shock pulse traveling through a structure which may cause damage at some distance from the explosion, knocking down walls and even removing brick columns. Such shock pulses may, in addition, destroy some of the bond between the steel and concrete of the intervening structure, with resulting weakening and possible failure of beams and columns.

When all the effects of bombs are considered, steel-framed structures are much more resistant to collapse than any other type. It is difficult to destroy by a bomb even a single important member of a frame, except by direct impact or when explosion is in contact with the member. A near miss simply scars the steel with fragments and perhaps displaces it by a few inches. The most serious effect results when a bomb bursts in the floor and displaces the base of a column. Here the damage may be widespread. However, if such a member were severed in a building designed in accordance with the principle of continuity, as mentioned previously, the damage would be local-

ized and more easily repaired. Experience abroad indicates that concrete members are more easily injured and are more difficult to repair than are steel members.

Brick or masonry wall-bearing structures, or any building where the walls support the floors and roof, suffer the greatest damage. Such walls are readily destroyed in considerable lengths by direct hits or near misses. As a result floors or roofs supported by them collapse, and usually the structures must be rebuilt. If brick walls are bonded to light steel columns, the result may be to distort the column as well as to destroy the walls, and the effect is similar to that above noted. If a bomb explodes above ground level, further damage may be caused by the collapse of floors and walls beneath because of the load of debris. In this way areas of damage produced by a single explosion may be multiplied.

The blast of bombs exploding on roofs or inside one-story factories usually destroys large portions of the roof. This is particularly true in the case of large areas of glass or asbestos cement roofing. The effect of blast with heavier types of roofing, more strongly attached, may be to distort structural members before the roof fails.

Internal damage of factories depends largely on whether factories are of the single-story or multi-story type. In the single-story industrial-type building the bomb may burst either on the roof or on the ground. The chief damage from bombs bursting on the roof is from bomb fragments projected downward and from the dislocation or destruction of roof trusses or girders. Bombs bursting on or in the ground are apt to displace and wreck machinery. Where each machine is individually powered, the damage is usually less extensive than where line shafting is used. In multi-story factories and similar buildings, such as warehouses, department stores, apartments, office buildings, etc., the bomb is apt to explode either in the top story or to penetrate two or three floors, exploding between them. Cases have occurred where six or more floors have been perforated by a bomb with a long-delay fuse. When the bomb explodes between floors, the confinement of explosion plays a very large part in the structural damage.

At one extreme, in very large structures with uninterrupted floor areas and high clearances, the explosion may occur almost as in free air and may do little or no structural damage. At the other extreme, bombs bursting in small rooms may completely disintegrate walls and ceilings.

Fire may result from attack by incendiary bombs or from dislocation and destruction of gas mains by action of explosive bombs. In non-fire-resistant buildings the hazard of fire and consequent dam-

age is usually great. In concrete frame structures this hazard is relatively less. Normal concrete construction is more resistant to fire than the unprotected steel work which is often found in industrial buildings. Steel frame buildings, built under modern building codes in which adequate fireproofing is provided, are, of course, less vulnerable to fire damage than unfireproofed steel buildings. It is said that in England for every ton of structural steel irreparably damaged by high-explosive bombs, 10 tons are destroyed by fire.

6. General Effects of Bombs on Utilities

Underground utilities suffer serious damage from earth shock and movement, which dislocates sections of pipe, caves in large diameter brick sewers, or breaks individual sections between joints. Underground utilities in the immediate vicinity of a bomb crater are usually completely shattered. Cast iron and steel water mains are often found with longitudinal splits in the pipe as well as transverse cracks. Gas mains, usually of cast iron, are badly damaged also.

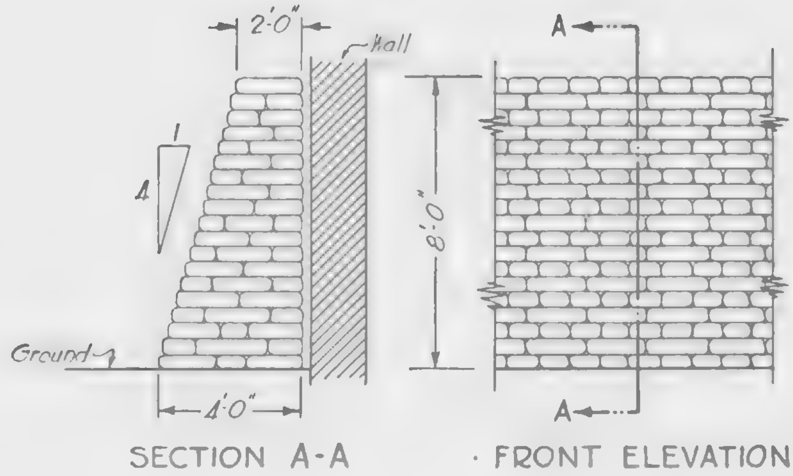
Sewers may continue to function, even after considerable damage, since they are ordinarily laid approximately to a hydraulic grade line and are not usually under pressure.

Underground telephone and telegraph cables suffer probably the least from the effect of bombs since the conductors can stand considerable displacement and bending without destruction. Power and telephone cables carried on towers or poles also suffer little damage unless supporting structures are destroyed. The destruction of insulators by bomb fragments may cause serious difficulties until the insulators can be replaced. Electric machinery and generating equipment in power plants are subject to damage by movement of foundations, and particularly by fragments. Oil transformers are vulnerable to damage from fragments piercing transformer casings. The result may be fire or destruction of the transformer.

7. General Effects of Bombs on Railroads and Bridges

Direct hits on railroad tracks result in limited damage which may be repaired readily. Terminal stations, switch towers, freight concentration and make-up yards, and tunnels and bridges are sensitive points. Destruction of or damage to these elements cause longer delays in the movement of traffic than destruction to track.

Steel-truss bridges ordinarily suffer only local damage from bombing and may be repaired readily. A few members may be cut and the rail bed displaced. In the case of a plate girder bridge a direct hit may bend one girder without destroying its serviceability. It is quite possible that a direct hit with a large bomb would destroy a small bridge.



1. *An average size sandbag filled measures approximately 20" x 10" x 5", but any bag suitable for filling with earth or sand can be used for this purpose.*
2. *If possible, an air space of about 2 inches should be left between the sandbag wall and the wall of building.*

FIGURE 3.—Sandbag wall to resist penetration by splinters.

II. MEASURES OF DEFENSE AGAINST AERIAL ATTACK

The second part of this bulletin is concerned with measures of defense against aerial attack. Consideration is given to the protection of buildings, to the protection of utilities and industrial plants, and to air-raid shelters.

A. PROTECTION OF BUILDINGS

It has been pointed out that framed buildings of steel or reinforced concrete construction are relatively much less affected even by direct hits than are buildings of wall-bearing construction. Modern public, commercial, and industrial buildings are usually of steel or concrete framed construction and should withstand bombing very well.

Bomb fragments may pierce building walls where the thickness is less than that indicated by table 4 (p. 8), and light wall panels and windows can be destroyed easily by blast. Usually protection can be given by sandbag walls, which are very effective in stopping fragments. Figure 3 (p. 13) shows a sandbag wall recommended for protection of the first floor of a building. It should be noted, however, that in climates subject to normal rainfall and snow, untreated sandbags deteriorate very quickly and usually disintegrate in a few months if exposed to weather. Therefore, sandbags generally should be considered as a temporary expedient to be replaced by brick or concrete walls when possible.

There is little that can be done toward making a wall-bearing structure safe from bombing. Sandbag barricades may protect the contents from fragments of bombs detonating outside the structure but they cannot prevent demolition of the entire structure by blast. Buildings of this type often have wood floor systems which add to the fire hazard.

In the design of new buildings *specifically to resist bombing effects*, the vulnerability of wall-bearing structures practically precludes employment of such structures in all but exceptional cases and it narrows the choice of structures to one where the frame is constructed of steel or reinforced concrete. If connections of the girders and columns are made strong and if the principle of continuity is followed, it is possible to design a building in which extensive collapse is very unlikely even under a direct hit of a very heavy bomb.[1]

The cost need not exceed materially that of a similar structure in the design of which no provision is made for the effects of bombs. Indus-

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[1] See Prof. J. F. Baker, "The Resistance to Collapse of Structure under Air Attack," Journal of the Institution of Civil Engineers (London), October 1949.

trial structures with light roof covering should be designed, if possible, so that the destruction of one main member, such as a roof girder or column, will not overload the adjacent members to the extent that spreading collapse results. The dangers of collapse can be reduced considerably if the connections of the roof member to the column are designed strong enough to permit considerable distortion of the column or lateral displacement of its base without failure of the connection.

Wall panels of one or two story industrial type steel or concrete frame buildings should not be bonded to columns or other structural elements since serious damage to the structure may result. The following paragraphs, quoted from a bulletin of the Department of Scientific and Industrial Research, are based on recent British experience in bombing raids.[2]

"The function of the external walls of a wartime building should be solely to protect the plant and personnel against the weather and against the effects of near misses. Whatever walling material is used is liable to be extensively destroyed by near misses, but provided it is properly designed, it is possible to confine the damage to the walling material alone and to ensure that it does not involve the structural framework of the building.

"Cases have occurred in which panel walls built into the webs of steel stanchions [columns] have been subjected to severe blast and have bowed the stanchions [columns] out, shearing off their cap connections and producing collapse of the roof.

"The ideal wall construction therefore consists of panel walls giving the code standard of lateral protection built independent of the steel framework so as to ensure that in the event of a near miss, they are blown in without involving the steelwork. This independence can best be achieved by casing the steelwork in concrete not bonded to the wall panels *. * *."

The protection against scattering of glass fragments of window or skylight glazing by adhesive treatment, such as muslin glued over the whole surface of glass, has proved effective. Any adhesive treatment should be extended over the frames surrounding the glass. Factories with glazed roofs present unusually dangerous hazards to workmen because of the possibility of fragments of glass falling within the factory. Chicken wire nets may be installed overhead in the interior as near as possible to glazing or roof, to catch fragments of glass and other shattered roof coverings falling from the roof.

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[2] Department of Scientific and Industrial Research, General Principles of Wartime Building, Wartime Building Bulletin No. 10 (London: His Majesty's Stationery Office, 1940), p. 6.

In the construction of new factories, skylights should be dispensed with, if practicable, and recourse had either to artificial lighting or to lighting from side windows.

B. PROTECTION OF UTILITIES AND INDUSTRIAL PLANTS

1. Utilities.

The protection of utilities so as to permit continuation of service under air attacks is of paramount importance in maintaining industry and production.

Utility organizations in regions where there may be danger of attack should make plans for the following:

a. Continuation of electrical service and measures to be taken to minimize the effect of bombing.

b. Measures of defense in the construction of new power installations to minimize the effects of bombing.

a. *Continuation of Service and Protection of Existing Facilities.*—One of the best methods of providing continuation of service is that of having all sources of power interconnected so that even complete destruction of an important plant would result in the minimum interruption to the power supply. All vital control apparatus and conductors should be duplicated in so far as is practical and should be so arranged that in the event of destruction of one unit, its duplicate could be put immediately into service. Another protective measure, where feasible, is to have replacement units and parts of equipment strategically located and designed for rapid transportation to replace a partially destroyed element.

The general statements made previously as to the relative vulnerability of, and means of protection for, various structures may be applied to power-plant structures. Such buildings are generally of frame construction and of fire-resistant materials. A reinforced-concrete roof 5 inches thick is sufficient to prevent penetration of a 2-pound incendiary bomb. The walls should be thick enough to give protection against bomb fragments (see table 4, page 8). Where walls are of insufficient thickness, a sandbag, brick or concrete wall may be provided, in addition to the existing wall, to increase the protection. Large windows may be made less dangerous by closing part of the opening with sandbags, or preferably, with concrete or brick walls. Individual power units such as generators and turbines may be given protection by sandbag or brick protective walls around each unit.

Massive concrete dams suffer little or no damage by aerial bombardment. In certain cases, head gates and spillway gates with

their operating mechanism, intake screens, or trash racks may be damaged; in these instances, a degree of protection may be provided by reinforced-concrete protective structures, although such installations are so varied that definite recommendations cannot be made.

High-tension lines are not easily destroyed or broken down by aerial bombing. Few direct hits can be made by enemy planes unless they have the most favorable conditions for attack and fly very low over and along the transmission right-of-way. Even in such cases, direct hits resulting in the destruction of the steel towers seldom occur. Towers are sometimes damaged by fragments of exploding bombs, but in most cases this damage is not sufficient to interrupt the power supply.

The comparatively few interruptions of power supply on transmission lines, which are usually caused by damage to the conducting cables or insulators, may be repaired quickly and the broken insulators replaced. When towers happen to be destroyed by direct hits, usually service can be restored in a very short time by providing temporary lines. Multiple transmission lines having different routings or widely separated rights-of-way, and selective relay protection for the different circuits, will reduce the interruption of power service to a minimum.

b. *New Construction.*—New buildings of permanent construction which house important equipment or operations should be of framed, fire-resistant construction, with walls of sufficient thickness to resist fragments and roofs at least heavy enough to stop light incendiary bombs.

Power-plant machinery and other vital equipment should be given protection against fragments. Provision should be made for adequate fire-fighting equipment, and for concrete fire walls or barriers to prevent such spread of fire as might happen when oil-filled transformers and switches are used.

The construction of outdoor stations should be arranged so that sectionalization or cutting off of damaged sections may be done quickly and service restored over undamaged sections. A wider separation of the more vulnerable units, such as transformers, will serve to decrease the liability and extent of damage. Outdoor substations preferably should be of latticed angle iron construction, and the transformers and oil switches may be protected by walls of concrete, brick, or sandbags as previously described.

These penstocks, gates, etc., which are particularly likely to be damaged, should have adequate control equipment and valves to localize the damage.

Outside flow line equipment, including penstocks, oil piping, gas pipes, and other vital appurtenances of hydroelectric plants should be placed underground or in strongly constructed concrete ducts or tunnels, wherever this is feasible and financially practical.

Steam plants are probably more liable to injury than hydroelectric plants, because of the vulnerability of boilers and auxiliary equipment, and because of high chimneys which may be destroyed, damaging the part of the plant on which they fall. Protection from bomb fragments for steam plants may be obtained, in general, by putting concrete or sandbag walls about boiler rooms and isolating as much as possible the various elements of the plant.

2. Special Measures for the Protection of Industrial Plants

In general, many of the points covered under the protection of buildings and utilities are applicable to industrial plants. Steam boilers, machinery, essential water and gas mains, switchboards, and electrical cables should receive special attention. Besides causing disruption of operations, the destruction of supply pipes by bombs might involve flooding or explosion.

The storage of highly inflammable material, such as gasoline, oil, or chemicals in tanks, should receive special consideration on account of the serious fire risk. This may involve the construction of dikes around tanks, placement of tanks underground, or removal of tanks to a less dangerous location.

Communications must be maintained for emergency service. Duplication of lines and location of telephones in shelter and first-aid stations are necessary for adequate control.

In most cases, sandbags will afford the simplest and most effective means of protection of essential machinery against fragments, but wooden boxes filled with sand are an excellent substitute. Where practicable, duplicates of vital machinery, tools, dies, and special fittings should be obtained, if not already available, and stored as additional insurance against interruption. These duplicates should be dispersed, and should be away from the main buildings.

As previously mentioned, incendiary bombs may be expected to pierce light roofs and burn on the floor of the top story. Although most modern industrial buildings are of steel or concrete construction and consequently less vulnerable to fire, the contents of many such buildings are highly inflammable. It is most important, therefore, to take all possible steps to reduce the risk of fire by having adequate portable fire-fighting equipment in addition to permanent installations which may be damaged. Reserve supplies of water in static tanks or other reservoirs should be provided. Stocks of inflammable material should be reduced as far as possible.

Study should be made of the problem of carrying on work if supplies of water, electricity, and gas from public or private sources should be interrupted by damage to producing stations or service mains. Auxiliary power plants should be provided and maintained in working condition. Duplication of power and communication lines, switchboards, and other utilities is desirable.

Protection for personnel by the construction of shelters, internal or external, will be discussed in section C.

C. AIR-RAID SHELTERS

In connection with air-raid shelters, consideration must be given to various problems of design, general requirements for shelters, shelters in existing buildings, and external shelters. Each of these subjects is discussed below.

1. Structural Design

a. *The Problem of Design.*—When a bomb *strikes* a structure, it possesses a large amount of kinetic energy (9 million foot-pounds for a 1,000-pound bomb dropped from 10,000 feet). When it *detonates* in contact with a structure, a much greater amount of kinetic energy is released (of the order of 30 times the impact energy). The problem of designing a roof slab or a side wall to resist such large amounts of kinetic energy is obviously a new one for engineers. Simple structural forms can be designed in terms of energy loads and energy capacities. Complex units involving a nonuniform state of stress, such as an ordinary beam, may be designed for energy loads, if the maximum stresses are below the elastic limit. The greatest amount of energy capacity is available for many materials in the plastic range, however, and consequently the problem of design in terms of energy loads may become highly involved. If stress states were uniform, it would perhaps be a simple matter to evaluate design units. Stress states in beams and slabs subject to high impact loads are nonuniform and it is difficult to determine surface energy capacities and the highly localized effects of impact and explosion.

Engineers have long recognized the difficulties inherent in "energy design" and consequently the practice of using equivalent static loads has been prevalent. There is a theoretical justification for the use of such loads on simple structural units subjected to small impact loads of low velocity. There is little evidence, however, to justify their use for the tremendous energy loads from bombs.

If any substantial percentage of the energy of impact or explosion were to be transmitted to the support of a slab, it is evident that

the problem would be one of designing a slab under extremely dynamic conditions with dynamic forces of an order heretofore undealt with by conventional structures. It would be necessary to resort to vibration theory and apply it to such fundamental units as plates or slabs, columns, walls, and footings. New theoretical investigations would be needed were such dynamics to be absorbed in a structure as a whole. Evidently very serious consideration would have to be given to the problems of deflection and to the matter of type of support, but to apply any such theory, it would first be necessary to know how much energy must be absorbed by such action as opposed to that which is absorbed locally.

Again, it must be remembered that the effects of the kinetic energy, presumably, are applied over very short intervals of time. A bomb on striking a highly resistant target, such as the concrete roof slab of a shelter, is brought to rest in a very short time, on the order of one one-hundredth of a second. It is evident that a slab heavy enough to resist penetration will move only a very short distance before the bomb is brought to rest and that the method of support will have very little effect on penetration.

Finally, even if very heavy strains are induced in the structural material beyond the region of local damage, it is possible that the duration of these is very short. There is altogether too little information on the behavior of materials under very rapid rates of loading and under high strain for very short times.

It is evident that it is unwise to try to apply any elaborate theory of design where so much is unknown. We need to know the distribution of energy as between local disruption of material and the structure as a whole; the nature of the strains imposed at points remote from the event and the time through which these strains are imposed; the effect of strain well beyond the elastic limit for very brief periods of time; whether resonance ever occurs, though this seems unlikely. All these matters are currently the subject of research. None of the questions has been answered with enough clarity to warrant any promulgation of results. As results become available, they will be published and interpreted.

The uncertainty of the problem does not make it hopeless, however, from the viewpoint of the designer. Engineers have faced similar difficulties before; and from a few observations and common sense they have been able to design structures which have been safe, even if not economical.

It is the belief of most persons who have been privileged actually to witness and study experimentally impacts and explosions and their results on slabs of concrete or steel, that a very large propor-

tion of the energy released is absorbed immediately by local effects. Such effects include deformation of the projectile case, projection of splinters, pulverizing of structural material immediately adjacent to the impact of explosion, expulsion of this material to great distances, and heat. If only a small portion of the energy remains to be absorbed by the structure as a whole, the dynamic structural problem becomes unimportant. At some ratio of energy distribution, it will happen that a slab which will resist penetration and explosion will be adequate automatically to take care of the over-all structural effects due to the residual energy.

Similarly, if the supports of the slab are of a nature calculated to resist lateral impacts and earth-movement loads, they, too, will take care of the dynamic loads without special analysis. As has been said, most trained observers believe this to be the actual case. Indeed there is some evidence of the sort of strain produced by projectile impacts throughout the structure of a concrete slab, and these seem to be entirely within the capacity of concrete to absorb, in addition to the permanent strain due to dead load. The evidence on the strains produced by explosion is less clear.

Therefore, where it is necessary to design at once structures to protect against a direct hit, the best rule of thumb is to design them to resist the local effects of penetration and explosion (see table 3, page 5), and then to make certain that they are able to carry with the usual factors of safety, the actual (often very great) dead loads. Slabs for such structures usually will be very thick and pass possibly outside the range of conventional assumptions in the design of slabs; but trained engineers will have no difficulty in dealing with this type of problem.

It is evident that some of the physical properties of concrete may affect the resistance to penetration and explosion; this, too, is under investigation. Various special types of reinforcement may improve the behavior of the slab, but these will be arrived at more safely through a knowledge of strain distribution than through invention. The provisions of an elastic layer between the burster slab and structure may assist or may not; and this, too, will be investigated. *There is no evidence from any foreign or domestic source that refined theory supported by anything like adequate investigation has yet been developed; it is part of the problem to develop it.*

It does not appear that blast pressures in air will have any important effect on structures of the type under discussion if they are designed for impact and explosion.

Fragments from bombs detonating near concrete structures produce penetrations in slab surfaces which are discussed elsewhere. But when

such fragments hit near edges of columns or beams or slabs, they tend to spall off large pieces of material and bare the reinforcing. It is entirely possible that several hits in the vicinity of a concrete structure might cause serious damage by fragment attrition, and it will be desirable to investigate ways of reducing this "chewing-off effect."

There remains the earth wave from a bomb detonating in the ground near a structure. These shocks really cannot be compared with earthquake shock. Although the waves and ground movements are of the same general nature, they are of much less amplitude and much greater frequency and acceleration. (Typical amplitude for earthquake, 2.03 inches; for quarry blast, 0.0113 inch; frequency for earthquake, ½ to 1 cycle per second; for detonation, 15 cycles per second; acceleration for earthquake, 0.4 g.; for 550-pound bomb, 300 g., at 15 feet decreasing rapidly with increase in distance.) The United States Bureau of Mines has made a long and admirable study of detonations in earth and has published many bulletins, of which perhaps the following will be of interest:

R. I. 3319, November 1936, Earth Vibrations Caused by Quarry Blasting, by F. W. Lee, J. R. Thoenen, and Stephen L. Windes.

R. I. 3353, November 1937, Earth Vibrations Caused by Quarry Blasting, Progress Report 1, by J. R. Thoenen and Stephen L. Windes.

R. I. 3407, June 1938, Earth Vibrations Caused by Mine Blasting, Progress Report 2, by J. R. Thoenen and Stephen L. Windes.

R. I. 3431, December 1938, House Movement Caused by Ground Vibrations, by J. R. Thoenen and S. L. Windes.

R. I. 3542, December 1940, House Movement Induced by Mechanical Agitation and Quarry Blasting, Progress Report 3, by J. R. Thoenen, S. L. Windes, and Andrew T. Ireland.

The remainder of this section is devoted to some empirical suggestions for specific parts of structures.

b. *Roof Beams and Slabs.*—Heavy local shear stresses may result from the impact and explosion of a bomb. Bending stresses are apparently of secondary importance. It appears that any ordinary roof structure designed to carry the dead load with the usual design stresses will be perforated before it will fail in bending.

The penetration of bombs of various sizes in concrete and earth has been the subject of considerable investigation abroad. Structures can be built thick enough to resist the most destructive bomb known, but such structures must be very heavy. Concrete designed to resist scabbing and explosion may require special reinforcing. A large number of small reinforcing bars, placed preferably in three dimensions, seems to be more effective than an equivalent weight of large bars in resisting fragmentation, diagonal tension, and shear. A grillage of reinforcing bars running in both directions near the bottom surface of the slab

perhaps will help to prevent scabbing and prevent large fragments from falling off. Soffit plates of flat, corrugated, or trough section have also been used for this purpose.

c. *Burster Slabs.*—It is a common practice to protect a structure by means of a separate burster course or detonating slab placed over it. The function of such a slab is to prevent penetration and to break the case when the bomb has a delayed-action fuse, or to cause detonation if the bomb has an instantaneous fuse. If the bomb case is broken by the impact with the burster slab, the explosive often functions as a low-order detonation, which reduces its explosive effect.

When a burster slab is used, *it must positively stop the bomb*, or else it may increase the bomb's effect, since the bomb will explode in the confined space between the slab and shelter with greater force. The thickness of burster slabs varies with the protection to be provided. Tests are now in progress on slabs of various thicknesses, strengths of concrete, and types of reinforcing which should determine the type and thickness required for protection against the several sizes and types of bombs. There should be only enough earth over the slab to allow for the growth of grass for concealment. More earth would tend to tamp the charge and increase the explosive effect.

The burster slab should extend beyond the structure a sufficient distance to prevent a bomb penetrating the earth and exploding near a wall or underneath the shelter. If the burster slab can be supported independently, the space between it and the shelter should preferably be empty, since it has been shown that air is the best medium for dissipating the gases and shock from an explosion. Generally speaking, it is impractical to provide separate support for the burster slab, particularly if the structure is large. In fortification design it has been the usual practice to place a fill of sand over the structure and pour the concrete burster slab on top of this fill. Adequate drainage should be provided to reduce the transmission of shock.

The layer of sand between the burster slab and the structure has the effect of spreading the load and reducing the unit load on the roof. Its inertia also has some effect in absorbing a portion of the energy of impact and explosion. The use of springs or cushions between the burster slab and the structure, in lieu of sand, has been suggested. Some reduction in the maximum pressure exerted on the roof of the structure is to be anticipated in this design, but it appears that the total energy transmitted will not be greatly affected by a cushioning course or springs. Since the action is extremely rapid in either case, the method of support may not have any appreciable effect. This will be investigated, however.

d. *Walls.*—When the burster course does not extend far enough beyond the shelter to provide lateral protection, walls below ground must be strong enough to resist the tamped effect of a bomb exploding in the ground adjacent to the wall. No exact design data in convenient form can be furnished at this time for determining the required thickness of a wall to resist tamped explosion. Some specific data should be available upon completion of tests now in progress.

Walls of buried or semiburied splinterproof structures should be designed to resist the earth shock and debris surcharge resulting from near hits. Preferably, they should be constructed of a material which will permit reasonable distortion without failure. Protection may also be given by use of an open trench or by filling in the space adjacent to the wall with brush or similar material.

Walls above ground may receive an oblique hit from a bomb. The required thickness to resist the reduced impact and untamped explosion is much less than that for the roof or wall below ground. Walls designed to give protection against bomb fragments only, should have the thickness shown in table 4 (p. 8).

e. *Foundations and Floor.*—Bombs may penetrate underneath foundations or floor slabs. The same considerations apply as in the case of walls subject to tamped explosion.

2. General Requirements for Shelters

Shelters range in size and accommodation from hastily excavated trenches offering a minimum of protection to elaborate structures housing thousands. It is not economical to provide complete protection against direct hits of heavy bombs except where large groups are accommodated. Splinterproof shelters which provide reasonable safety at low cost should be designed and built to give complete protection from the following:

(1) Blast and splinters of a 500-pound bomb exploding not nearer than 25 feet.

(2) Direct hit of a light incendiary bomb.

(3) Debris from adjacent falling buildings.

(4) Earth shock from a 500-pound bomb exploding not nearer than 25 feet.

(5) Gas.

When shelters are built for capacities greater than 50 persons, or are located in particularly dangerous areas, protection should be greater in proportion to the number of persons and relative danger.

There are a few general requirements for shelters, which apply to any type, whether in buildings or outside. Entrances to shelters should be numerous and large enough to allow all persons for whom

the shelter is intended to enter in the period between the time the warning is sounded and the raid begins. No matter how small a shelter is, there should be at least two means of egress, since one may be barred by debris. In any structure housing more than a few people, there should be a means of allowing passage into the shelter without permitting gas to enter. This is usually provided in larger shelters by use of a double set of doors in a short passageway. The person entering closes the first door before opening the second one into the shelter. It is preferable to have a right angle bend or offset in such gas locks so that splinters passing through one door will not pierce the other. In shelters designed expressly for the purpose, the doors may be of steel, heavily constructed, and gas tight. In improvised shelters in existing buildings, doors should be weather-stripped and all cracks and keyholes plugged. Heavy blankets hung across door openings and held in place by boards may afford some protection in an emergency. These light closures are likely to be blown in by blast, however.

It is desirable to have provision for decontamination at the entrance to the shelter leading off from the gas lock so that persons exposed to persistent gases may wash and change their clothing before entering the shelter room.

The importance of ventilation in shelters depends on the capacity of the shelter, the likelihood of gas attacks, and the probable duration of a raid. Even when gas is not used, some positive means of ventilation is desirable to expel carbon dioxide and moisture. Although natural ventilation is cheaper than artificial, a shelter relying on natural ventilation must be much larger per capita, for the presence of gas requires the sealing up of all places where air may enter, and the air inside the shelter must be sufficient to support respiration during the period of the raid. Continental authorities generally agree that persons in a hermetically sealed room require a minimum of 35 cubic feet of air per person for 1 hour's occupancy. Continued occupancy for a longer period causes serious physiological disturbances.

Filtration units are required to provide gas-free air. Units should deliver not less than 180 cubic feet of air per person per hour;[3] if electrically driven, they should have provision for manual operation. Air is pumped in from the outside and passes through filters which absorb the poisonous gases. The air then passes into the shelter and exhausts through suitable ducts. A slight positive pressure is maintained to prevent the entrance of gas-laden outside air. The life of the filter depends on the concentration of gas and the moisture content

[3] For occupancies of greater than three hours' duration, the ventilation rate should be increased to not less than 450 cubic feet per person per hour.

of the air passed through it. Gas collects in low places, and the concentration of gas decreases at higher points. Therefore, it is advisable to have the intakes at least ten feet above ground so that they can draw in clean or less contaminated air. More than one intake should be provided, since one may be damaged or destroyed.

In any but an emergency shelter, lavatories and toilet accommodations should be provided. In shelters above ground the disposal may be to the regular sewers, but in shelters below the ground the sewers will probably be too high, and disposal must be obtained by chemical closets, septic tanks, or by drainage into special sewers.

Electricity should be provided from the regular mains for lighting and for operation of ventilating-fan motors, but auxiliary power should be provided also. This auxiliary power may be from engine-driven generator sets or, in small shelters, from storage batteries. If a generator is used, it should be separated from the main room of the shelter, and the exhaust from the engine piped outdoors.

Water supply may be from the city mains also, but a second source is desirable. This source may be a storage tank under the shelter. Water should be available in sufficient quantities for drinking and washing and in larger shelters for showers.

Beside the above-mentioned utilities, equipment in a shelter should include food stored in airtight containers, and crowbars, picks, and shovels for digging out should the entrances become blocked. All shelters should have first-aid kits and the larger ones should have a sick bay with beds and trained personnel. Decontamination rooms should have supplies of clean clothing and bins for contaminated clothing. Telephones should be provided in the larger-sized shelters. Radio is likely to be an important means of communication in war, and shelters may be equipped with receiving sets, although more essential items should be provided first.

3. Shelters in Existing Buildings

It has been pointed out that steel or concrete framed buildings are relatively safe from anything but a direct hit from a high explosive bomb, and the convenience and relative economy of a shelter inside a building may be determining factors in selecting the location of a refuge. Shelters within buildings have the advantage that they are easily accessible to occupants of the building and can be kept warm and livable. With a few exceptions, modern office, factory, and apartment buildings of more than four stories are usually of reinforced concrete or steel frame construction and offer suitable and very accessible locations for shelters within the building.

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The room selected for a refuge should have its ceiling strengthened to support any debris loads which may come upon it, and lateral protection should be obtained by closing up window and door openings with concrete or brick or, in an emergency, with sandbags. Preferably, no gas or steam conduits should enter or pass through the room. The amount of bracing or shoring necessary to withstand debris loads is quite large. English and German specifications require strengthening to carry a load from 200 to 400 pounds per square foot in masonry buildings. In framed buildings this could probably be somewhat less.

In some buildings basements are particularly suited for refuge rooms. Basements offer the greatest lateral protection from blast and splinters, and the floor overhead may afford protection from light bombs. On the other hand, the weight of debris is likely to be greatest on the basement, and there is danger from heavy gas collecting in low regions. Water and sewer mains bursting nearby constitute another danger. The possibility of fire in buildings of nonfireproof construction should be borne in mind. The decision as to whether the basement should be used as a shelter must be made after consideration of the factors present in each specific situation.

In some steel or concrete framed buildings the intermediate floors (for example, the second or third floors in an eight-story building) are well suited for shelters. A special case is that of a very narrow building which may not offer any suitable shelter. Floors at intermediate levels have the important advantage of being generally above the level of gases, and the danger from splinters is decreased. It is probable that in many buildings such locations would be more accessible to all the occupants. Furthermore, the weight of material overhead is not so great as it would be over a basement location; so less shoring up of the ceiling is necessary. Even in the event of a direct hit, the bomb may explode on the roof or pass through to the basement, leaving the shelter little damaged. The danger of being trapped in the shelter would probably be less than in a basement structure. Also, the fact that close watch could be had on the progress of the raid from lookout windows would be important for directing operations and assisting fire and decontamination squads.

It is suggested that in a large building several small shelters be constructed in preference to one large one. This arrangement facilitates entrance and egress and prevents total loss of life if one shelter is hit. Shelters may be located advantageously in corridors; they are usually easy of access and are given lateral protection by having two or more thicknesses of wall between them and the outside. Some modern office buildings have staircases located centrally with no open-

ings except a door at each floor. These suggest themselves as excellent places of refuge, since they can be reached from each floor, give good lateral protection, and their general usefulness is not impaired.

Shelters in basements should have at least one emergency exit that does not open into the building. A tunnel leading from the shelter room to a manhole some distance from the building is satisfactory. An area window which has been closed up by sandbags or loose brick also can be a means of escape. In connected buildings an emergency exit may be made by cutting through a party wall. It occasionally happens that separate buildings of a single organization are connected by utility tunnels. These tunnels may afford emergency exits and can be used even as shelters if sufficient cover exists and steam, gas, and other conduits can be closed.

A building that is not of fire-resistant construction should not be used for a shelter unless it is impossible to find protection elsewhere. In such a case the attic or space under the roof should be cleared of all inflammable material and equipment should be provided for fighting fire. An incendiary bomb can pierce easily a slate or tile roof but it may lodge on the attic floor. The British Air Raid Precautions Department advises covering the floor with two inches of sand if no better covering can be used.

In the selection of a room to be used for a shelter, attention should be paid to the possibility of heavy loads falling onto the shelter as a result of the destruction of supporting members.

Figure 4 (p. 30) shows some characteristic features in a typical industrial area which are potential sources of danger, and areas that are well located for shelters. These are discussed below.

Area A is a good location for a splinterproof shelter. The overhead protection is insufficient protection against a direct hit, but there is good lateral protection which can be improved by sandbag or concrete walls. It is centrally located and can be reached conveniently by all the occupants of the building.

Area B should be avoided, since injury to columns abnormally exposed would lead to local collapse, resulting in heavy debris loads on the ground in that area. Hence it would be difficult to provide for emergency exists.

Area C is unsuitable for shelter because it would be flooded rapidly if the canal wall were injured, and because it would be liable to be crushed by the fall of the heavy water tank.

Area D is unsuitable because of its proximity to the base of the water tank and because it will rarely be economical to strengthen the roof of the shelter to withstand the fall of the heavy machinery on the upper floors.

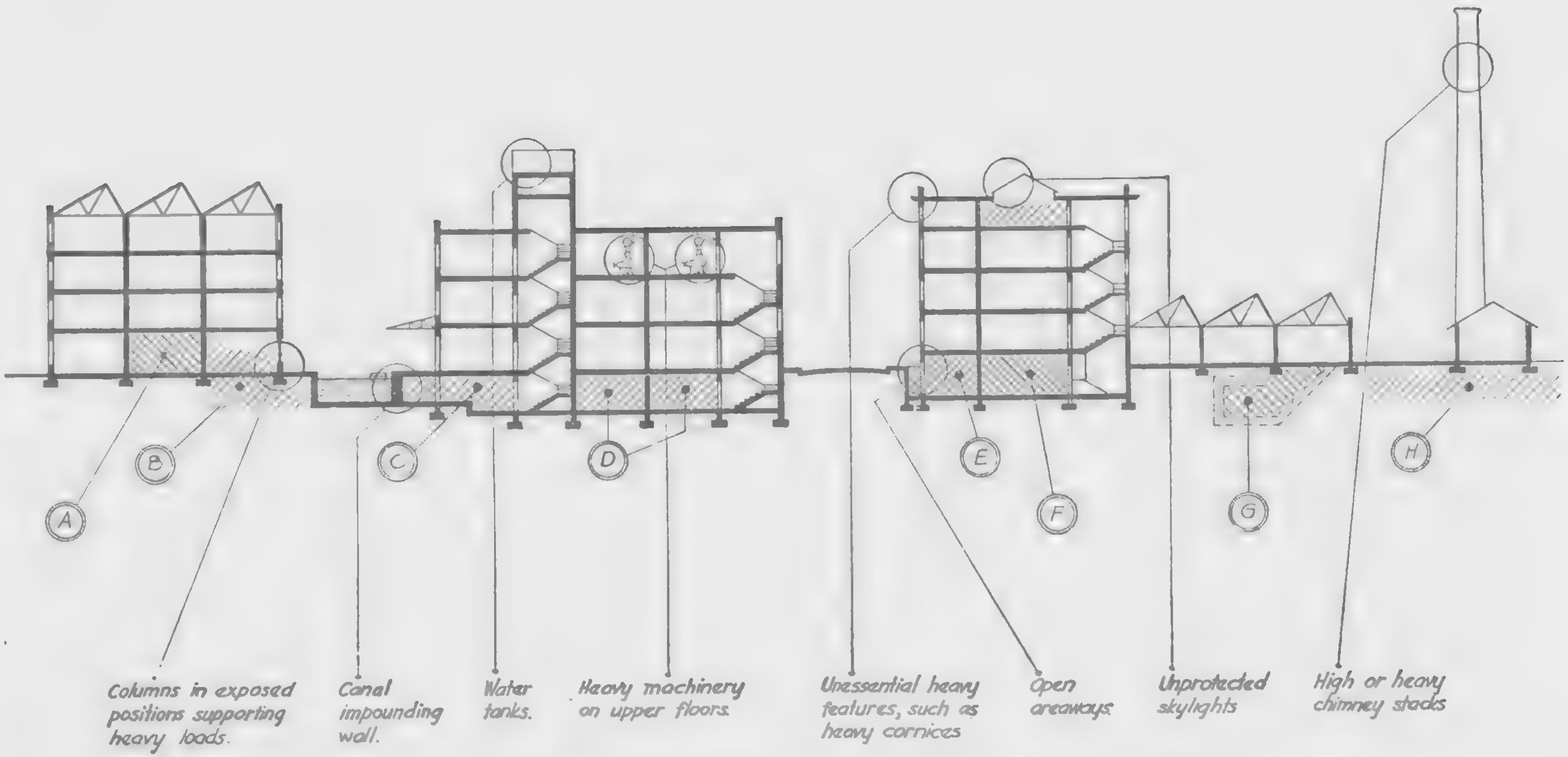

FIGURE 4.—Some features of buildings in an industrial area that affect the selection of locations for shelters.

Area E might be a dangerous location due to the possibility of collapse of the heavy cornice and parapet, and the open areaway would give less than standard lateral protection.

In the case of area F, inflammable construction or the storage of inflammable material immediately under the skylight might present a fire hazard which could endanger the whole building. If proper precautions were taken with respect to fire protection, area F would be a good location for a shelter for the same reason applies as to area A.

In the case of area G, the light construction of this building precludes the use of any section as an air-raid shelter. This situation necessitates the construction of a separate shelter, either under the building, as shown, or elsewhere.

Area H, at the base of a large chimney, is unsuitable for the location of shelters, due to the possibility of large debris loads.

In general, it may be said that shelters within buildings can be constructed to give approximately the same degree of protection and convenience that can be afforded by external shelters. The choice of the best type of shelter for any given case must be governed by local conditions.

4. External Shelters

There may be many cases where the use of existing buildings for shelter purposes is impractical, inconvenient, or even impossible. Old buildings of poor construction or buildings vulnerable to fire or near important targets are worse than none at all.

External shelters may take the form of long, narrow tunnels or may be large, rectangular buildings. They may be above ground, partly buried, or many feet underground. They may be designed to give almost any degree of protection. Shelters below ground give good protection laterally and offer the least disturbance to the present use of the ground surface. If sufficiently deep, economies in concrete may be effected, since the earth above gives protection. This economy is more than likely to be offset by increased excavation costs, however. Disadvantages to building shelters underground are the danger from gas and bursting water mains, and underground utilities may be so crowded that there may be no room for shelter.

Designs of four air-raid shelters are shown in figures 5 to 8, inclusive (pp. 37 to 43). These designs are based on current European practice for *splinterproof* structures and are being tested to determine the degree of protection afforded. It is believed that these shelters will provide protection from the effects of demolition bombs exploding not closer than 25 feet, including such effects as blast, splinters, earth shock, and debris from falling buildings.

All four of the shelters have a door which can be made gastight, and although no ventilation equipment is provided, the cubic capacity of the shelter is such as to provide sufficient air for occupancy of not more than one hour.

Three of the shelters (see figs. 5, 6, 7, and 8, pp. 37 to 43) are provided with an emergency exit in addition to the main door. This exit is for egress in event the main entrance is blocked by debris or is otherwise unusable. Shovels, picks, or other excavating tools should be provided to assist in digging out.

The shelter shown in figure 5 is designed for use where it is possible to bury the structure completely or where it is not desired to interfere with the present use of the area by the construction of a semiburied or surface structure. Its cost is in the neighborhood of $750.

The shelter shown in figure 6 was designed with the possibilities of mass production in mind. The main body of the shelter is built from standard corrugated iron plates such as are used in culvert construction or for tunnel liners, the end walls are made from steel plates, and the entrance is through a standard 36-inch corrugated iron pipe. Two alternate arrangements are indicated, one or the other of which may be advantageous in certain locations. It is estimated that the cost of this structure is about $250.

The shelter shown in figure 7 utilizes commercial corrugated iron sheets. Its base is made of 4 inches x 4 inches lumber and is not watertight. The end walls are five-eighths-inch plywood. The approximate cost of this shelter is $230.

The shelter shown in figure 8 is a circular corrugated iron structure similar to the structure shown in figure 6, but has concrete end walls and a ramp down to the entrance. A ramp is preferable to stairs because of the added safety. This shelter costs approximately $400.

Air-raid shelters of the small six-person type are suitable for residences or in areas that are relatively sparsely populated.

These shelters are not practical, however, where large numbers of people congregate, such as in apartment houses, factories, office buildings, etc. In most such cases, shelter can be provided within the buildings, as has been mentioned previously, but in a good many instances external shelters must be provided, and for large numbers of persons protection should be relatively complete. British standards of protection require that not more than 50 persons be accommodated in a single *splinterproof* shelter, and that such shelters should be separated by not less than 25 feet.

The six-person shelters shown in figures 5 to 8, inclusive, can be extended to accommodate larger numbers. Shelters shown in figures 5, 6, and 8 are particularly capable of enlargement. The length of

each structure should be increased 2 feet 0 inch for each two additional persons accommodated, and provision should be made for ventilating equipment and chemical toilets. Figure 9 (p. 45) is a lay-out of independent splinterproof shelters situated in accordance with the British code and is applicable to locations such as factory districts where large numbers must be provided for.

A most economical external shelter is one roughly rectangular in plan, designed to give protection against a direct hit from a medium sized demolition bomb. This shelter may be situated in parks or other open spaces and can be built to accommodate large numbers of persons. The maximum capacity of such a shelter should be determined by the number of persons that can get to the shelter in a reasonable time. Shelters of this type should have several entrances to prevent congestion. Ramps are preferable to stairs as there is less danger of falling in the rush to get into the shelter. All the previous remarks relating to toilet facilities, ventilation, food supplies, and decontamination are applicable. It may also be advantageous to provide sleeping accommodations. Any further accommodations, such as provisions for entertainment and recreation, may be of great value in maintaining morale and spirit, and should be provided when possible. Figures 10 and 11 (pp. 47 and 49) are designs of two bomb-resistant structures. Both shelters are believed capable of resisting a 500-pound bomb. These shelters are designed to accommodate 100 and 200 persons, respectively, and each one can be increased in length and additional galleries added so as to house a much greater number.

Shelters may be built above ground with pitched roofs, the purpose of these roofs being to deflect bombs. However, it is impossible to tell whether the bomb will strike at an angle such as to be deflected or whether its path will be perpendicular to the roof surface. Furthermore, it is likely that the retardation caused by deflected impact will detonate the fuse. If the bomb has an instantaneous fuse, it will explode with the same force against the sloping roof. If it has a delayed-action fuse, it will be deflected, but may explode in a nearby building.

Tunnels may be constructed to advantage, but must go quite deep if safety is to be assured. (See table 3, p. 5.) In most cities water will become a problem long before the required depth for safety is reached, and the earth will doubtless require extensive timbering. If tunnels are used, however, frequent independent exits should be provided, and particular protection given against gas. Tunnels running under or parallel to streets should have several entrances located some distance apart to facilitate serving each large area, in case part of the tunnel is blocked. The effect of blast caused by a direct hit in a tunnel

may be minimized by making the tunnel zigzag or crenelated in plan or by providing curtain walls, although such a form occupies more space.

In London certain portions of the subway system are being used as shelters. The subways there are tunneled through clay and usually are deep enough below ground to provide adequate protection. In general, subways in the United States could not be employed as bomb resistant shelters, owing to the shallow depth of cover, which would be insufficient protection against a direct hit of a bomb.

If possible, shelters should be designed with a view to use in peacetime. Multi-story garages, the lower floors of which may be used for air-raid shelters in time of war, have been suggested. Shelters near factories are expected to have a peacetime use as storage sheds. Refuges near banks and in financial districts may do service as vaults or depositories for precious metals. Shelters may be designed with the idea that buildings will be built later on top of them, the shelter serving as a basement. All these schemes have been advanced so that some benefit might be realized in peacetime for the rather large cost of construction of shelters. However, provision for peacetime use should not be permitted to decrease the efficiency of the shelter as such, and materials stored in shelters should be easily and quickly removable.

BIBLIOGRAPHY

The Office of the Chief of Engineers of the War Department has a very large bibliography of secret, confidential, restricted, and highly technical information gathered through research and reports of observers. For obvious reasons, many of these reports cannot be made generally available; others are highly specialized in their interest. It is believed that the selected list below will meet general needs for information.

Publications issued by the Air Raid Precautions Department of the Home Office (London: His Majesty's Stationery Office):

A. R. P. Handbook No. 5, Structural Defence (1st ed., 1939), viii, 58 pp.

A. R. P. Handbook No. 5A, Bomb Resisting Shelters (1st ed., 1939), vi, 6 pp. plus diagrams.

A. R. P. Handbook No. 6, Air Raid Precautions in Factories and Business Premises (1st ed., 1936), 69 pp.

A. R. P. Memorandum No. 10, Provision of Air Raid Shelters in Basements (no date), 38 pp.

Air Raid Precautions for Government Contractors.

Wartime building bulletins of the Department of Scientific and Industrial Research, Building Research Board (London: His Majesty's Stationery Office, 1940):

No. 1, Economical Type Designs in Structural Steelwork for Single Story Factories, 29 pp.

No. 2, The Application of Reinforced Concrete to Wartime Building, 9 pp.

No. 3, Type Designs for Small Huts, 22 pp.

No. 4, Supplementary Type Designs in Structural Steelwork for Single Story Factories, 19 pp.

No. 5, Economical Type Designs in Reinforced Concrete for Single Story Factories, 13 pp.

No. 6, Part 1, Arch Construction without Centering, Part 2, Further Designs for Hut Type Buildings, 9 pp.

No. 7, House Construction, 14 pp.

No. 8, Part IA: Walls for Factory Buildings; IB, Columns for Factory Buildings; II, Tubular Steel Trusses and Purlins for Factory Buildings; III, A System of Heating for Wartime Factories, 16 pp.

No. 9, Conservation of Cement and of Clay Bricks, 22 pp.

No. 10, General Principles of Wartime Building, 28 pp.

Publications of the Institution of Civil Engineers (London: The Institution):

Anderson, David, Lecture on the Design of Bomb-Proof Shelters (1939), 14 pp.

E. A. R. P. Memorandum No. 1, Blast.

E. A. R. P. Memorandum No. 2, Penetration of Bombs.

Glover, C. N., Civil Defense (London: Chapman and Hall, Ltd., 1940).

Samuely, Felix James, and Conrad Wilson Hamann, Civil Protection; the application of the civil defence act and other government requirements for air-raid shelters (London: The Architectural Press, 1939), 165 pp.

NOTE.—It is understood that the publications listed above may be purchased through The British Library of Information, 50 Rockefeller Plaza, New York City; Brentano's Book Stores, Inc., 1 West 47th Street, New York City; or any house dealing in foreign publications.

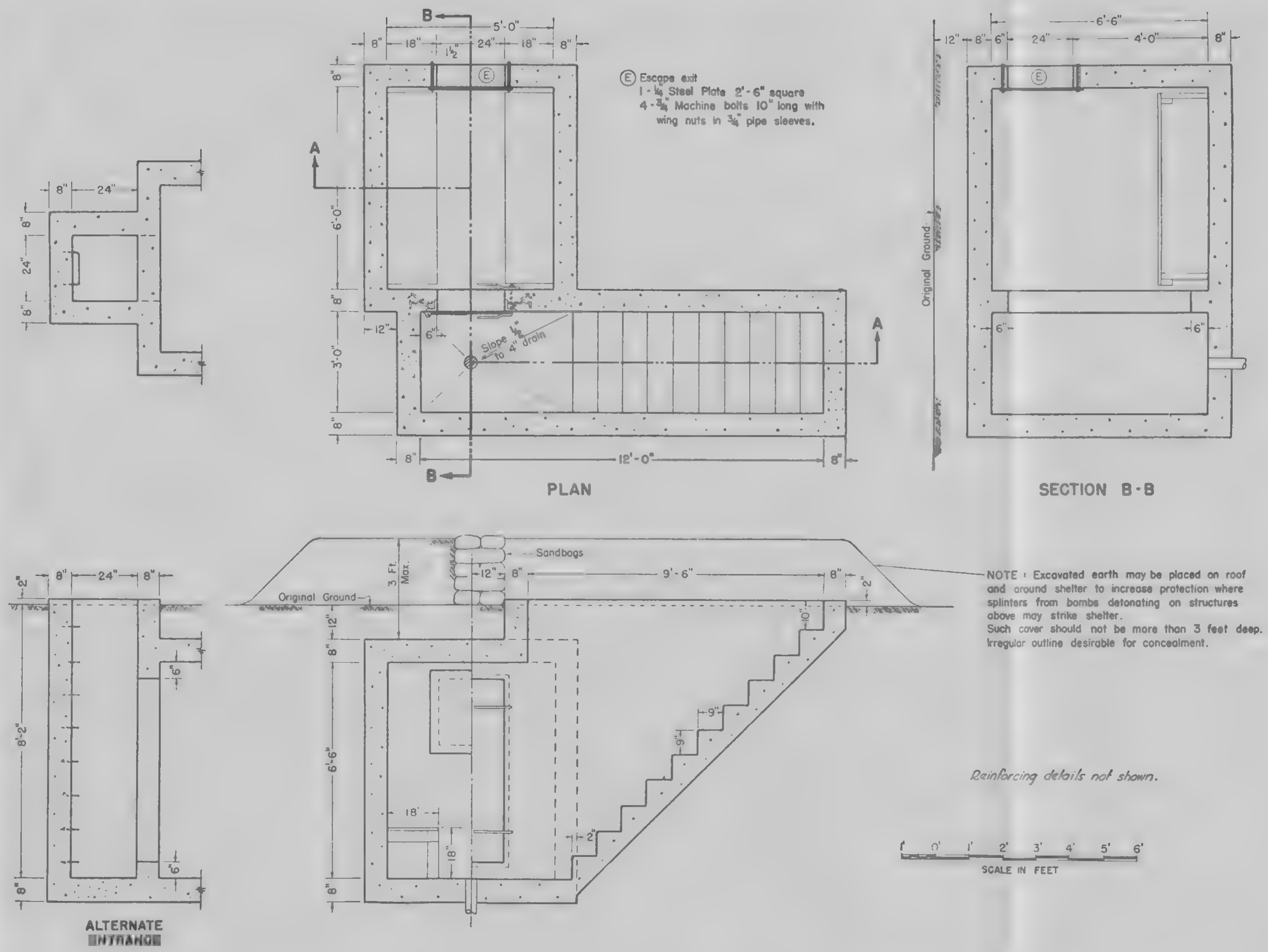

FIGURE 5.—Buried splinterproof air-raid shelter for six persons.

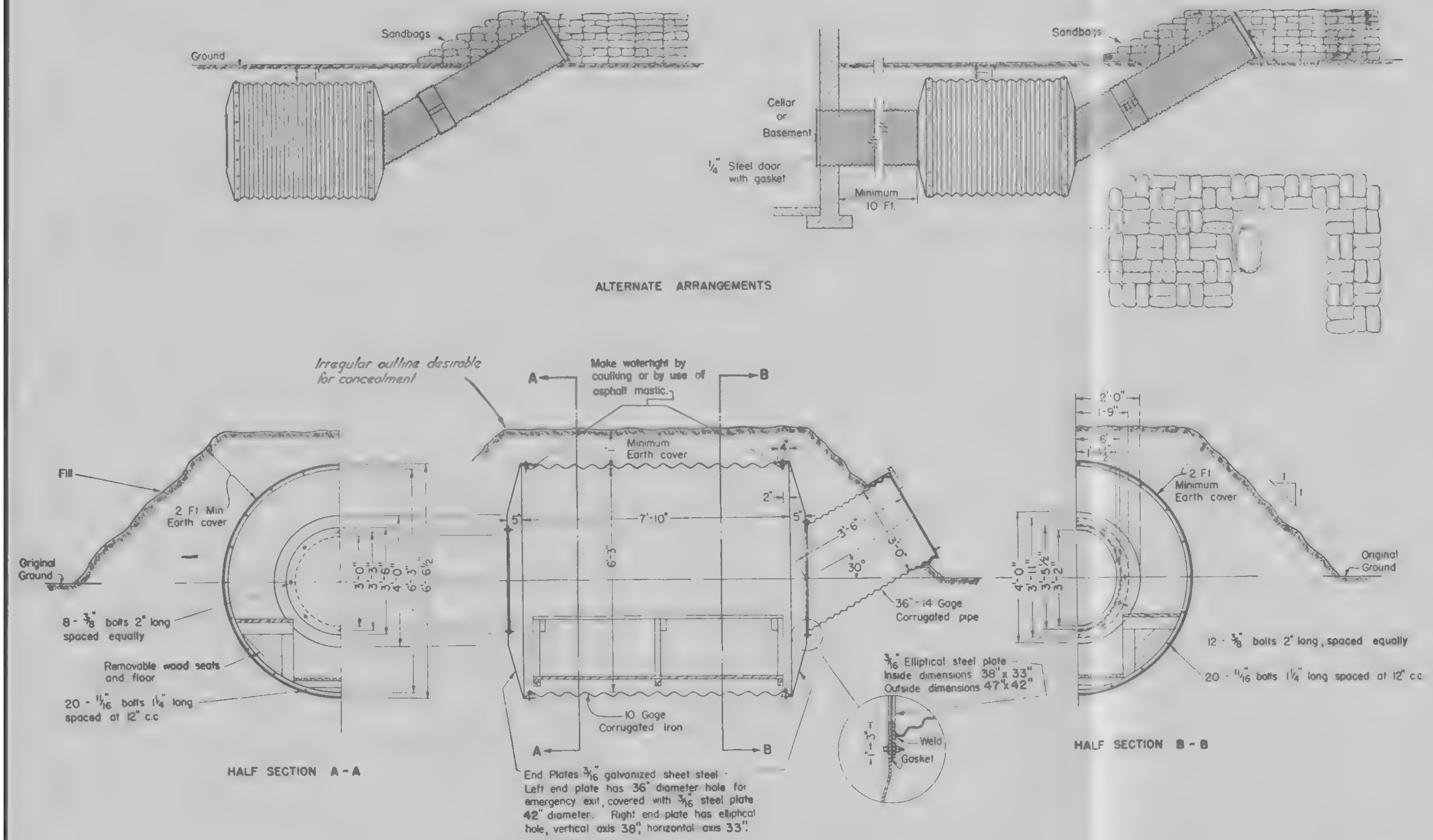

FIGURE 6.—Semiburied splinterproof air-raid shelter for six persons.

310135° (Face p. 36) No. 2

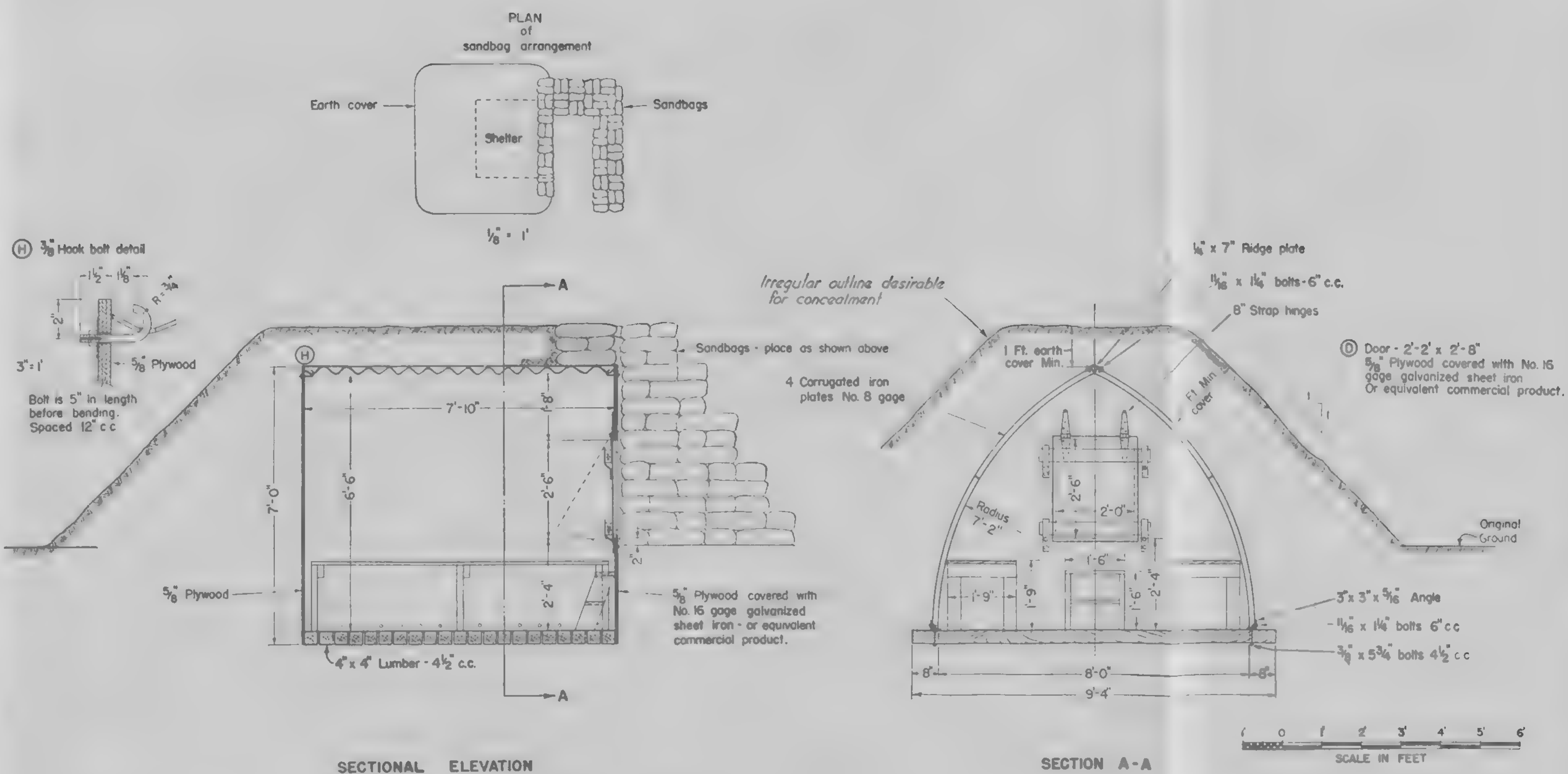

FIGURE 7.—Semiburied splinterproof air-raid shelter for six persons.

310135° (Face p. 36) No. 3

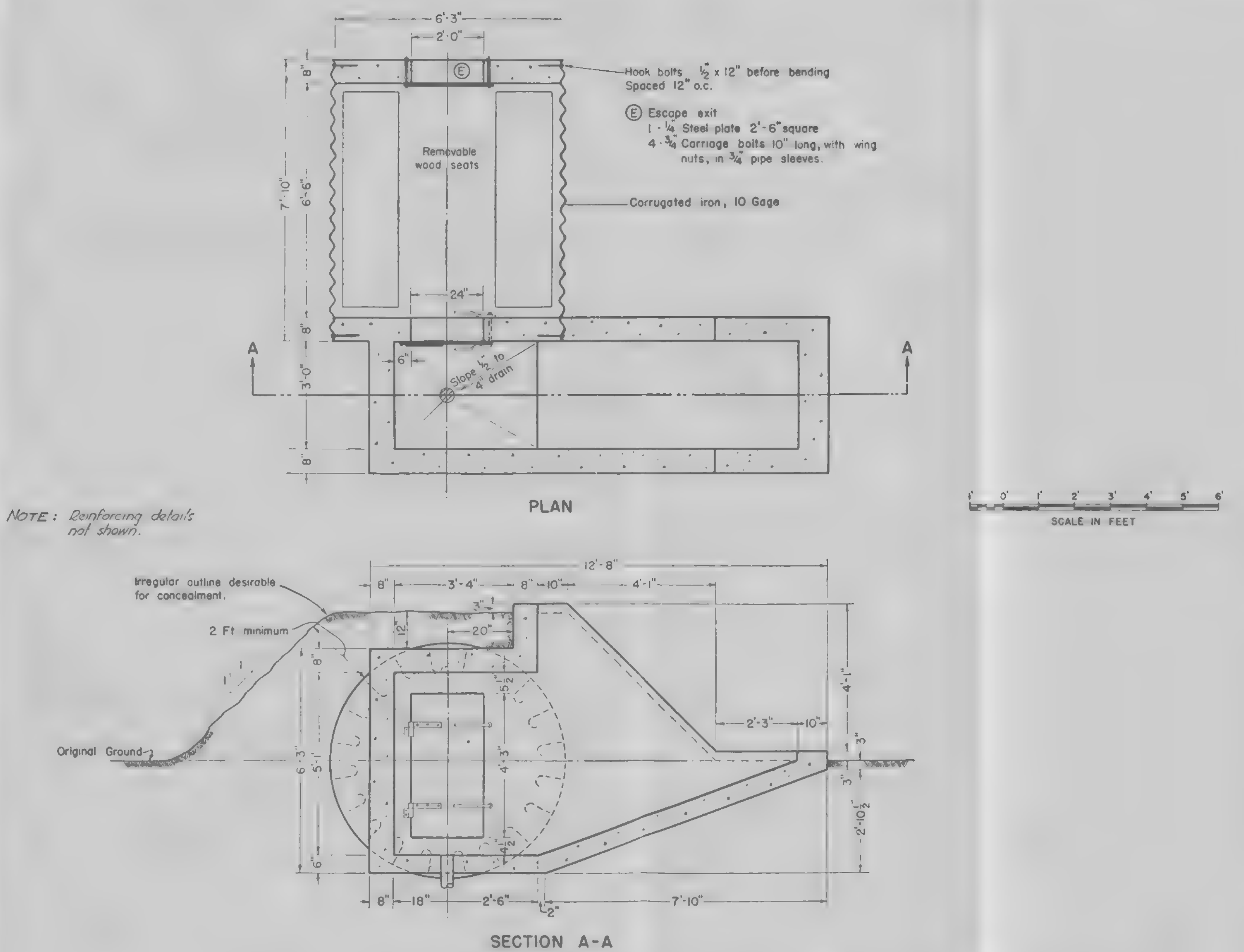

FIGURE 8.—Semiburied splinterproof air-raid shelter for six persons.

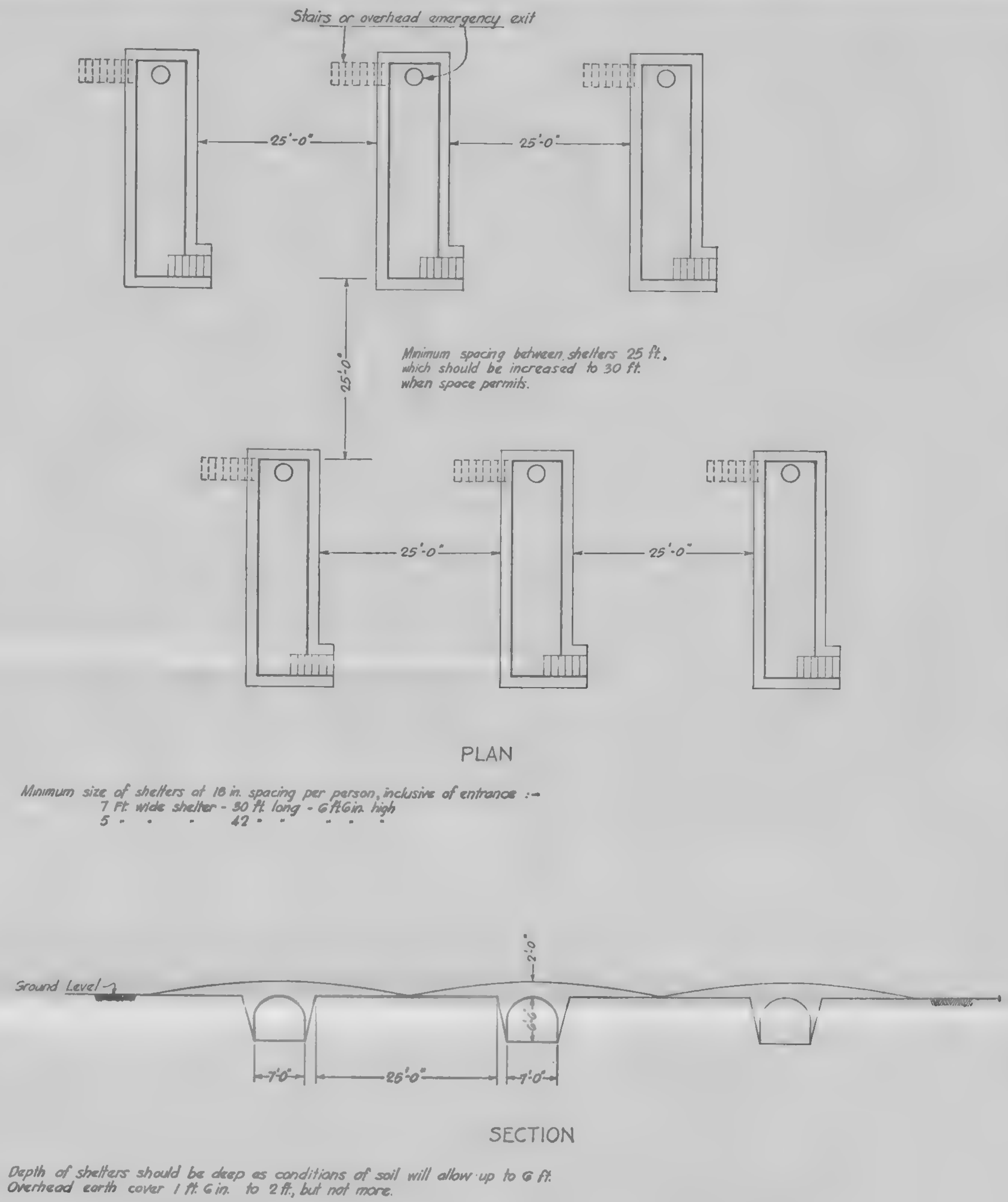

FIGURE 9.—Lay-out of independent splinterproof shelters, each accommodating 50 persons.

310135° (Face p. 36) No. 5

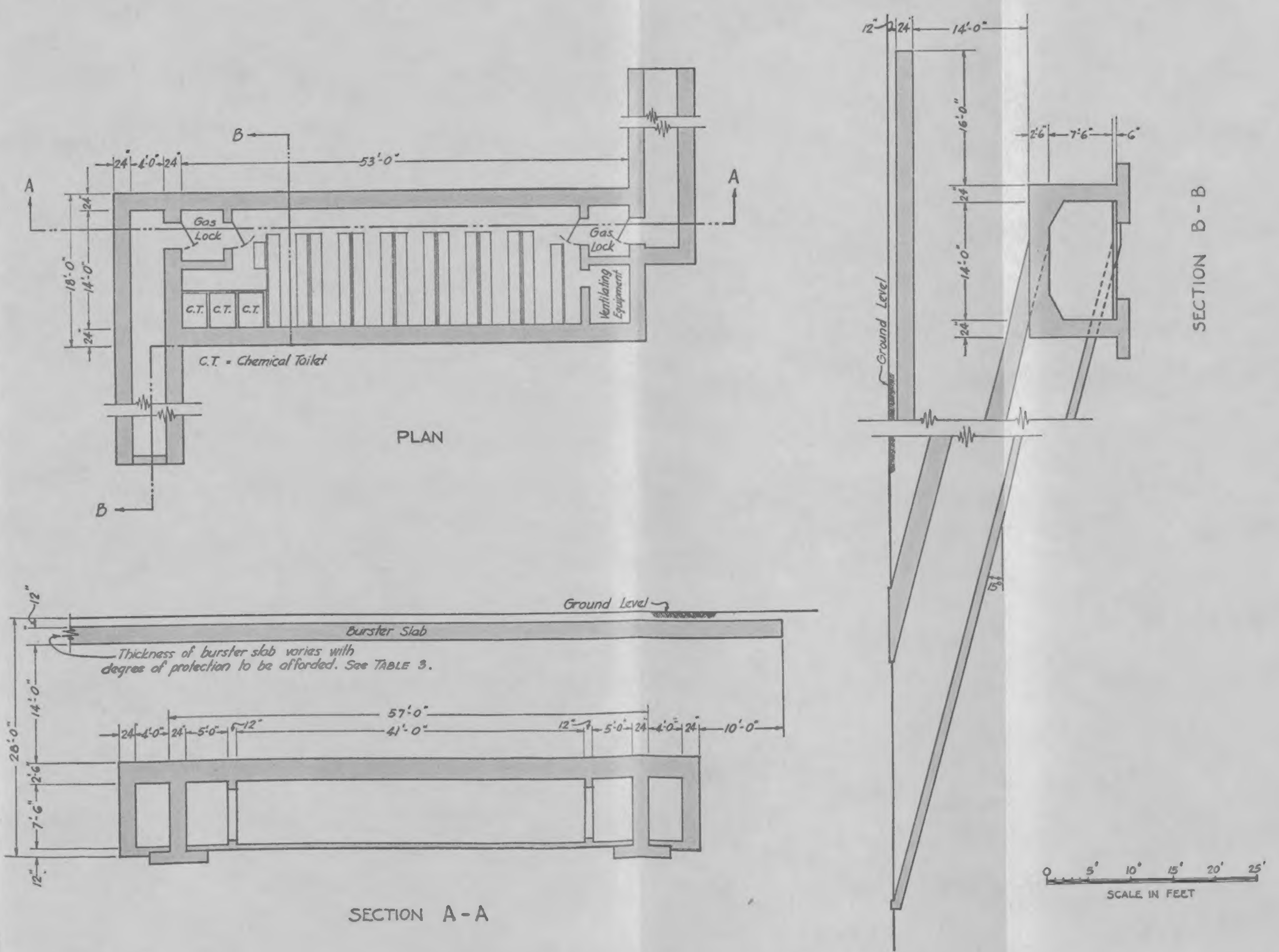

FIGURE 10.—Bomb-resistant shelter for 100 persons.

310135° (Face p. 36) No. 6

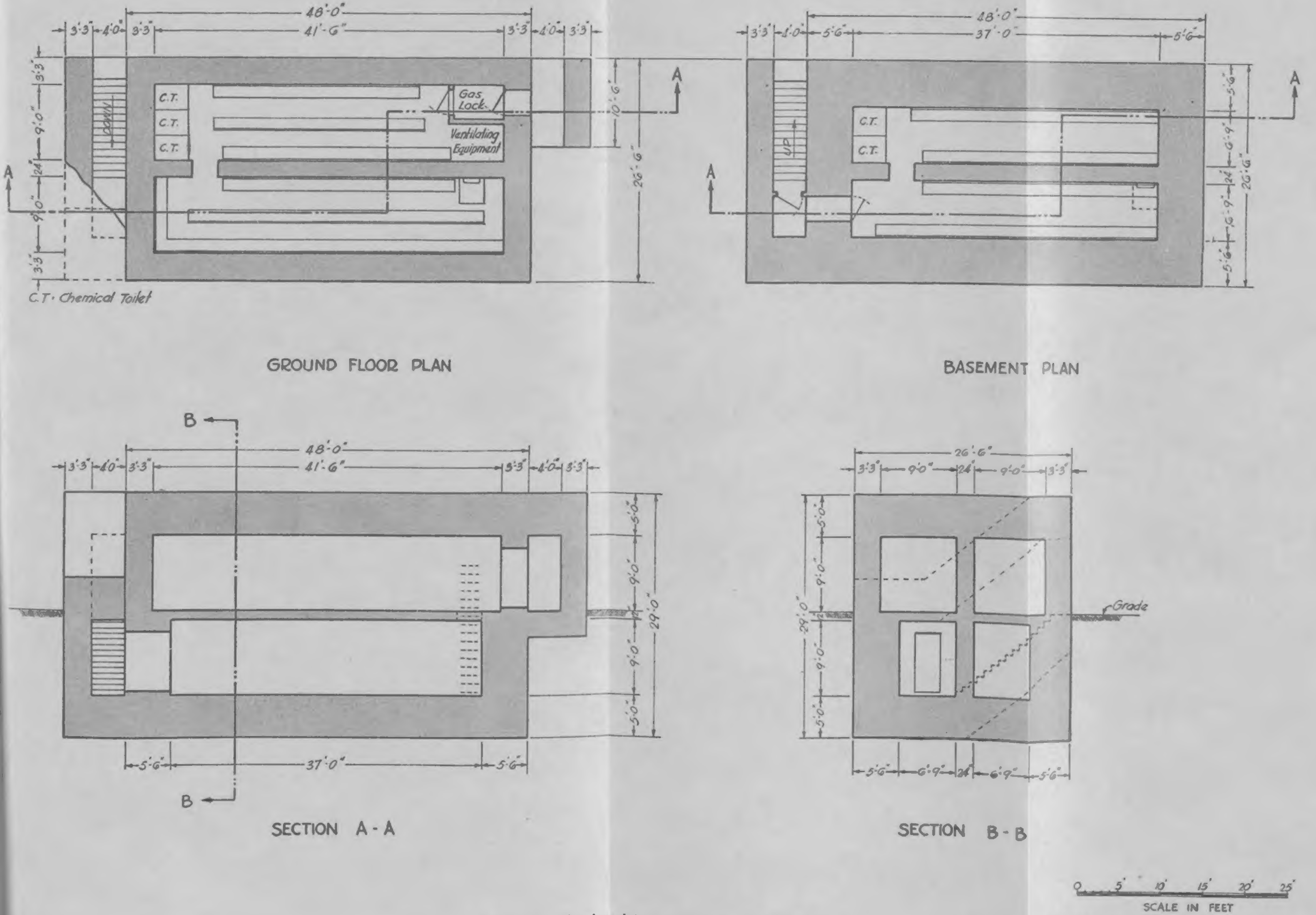

FIGURE 11.—Bomb-resistant shelter for 200 persons.

310135° (Face p. 36) No. 7